NORTHWEST CROPS & SOILS PROGRAM

2014 Organic Hop Variety Trial: Results from Year Four

Dr. Heather Darby, UVM Extension Agronomist
Julian Post, Lily Calderwood, Erica Cummings,
Scott Lewins, Susan Monahan and Sara Ziegler
UVM Extension Crops and Soils Technicians

(802) 524-6501

Visit us on the web at
www.uvm.edu/extension/cropsoil/hops

UNIVERSITY OF VERMONT EXTENSION
CULTIVATING HEALTHY COMMUNITIES

INTRODUCTION

Great interest has been kindled in producing hops in the Northeast. While hops were historically grown in the Northeast, they have not been commercially produced in this region for over a hundred years. With this loss of regional production knowledge, the advancements of cropping science, and the development of new varieties over the last few decades, a great need has been identified for region-specific, science-based research on this reemerging crop. The vast majority of hops production in the United States occurs in the arid Pacific Northwest on a very large scale in a dry climate. In the Northeast, the average hop yard is well under 10 acres and the humid climate provides challenges not addressed by the existing hops research. Knowledge is needed on how to produce hops on a small-scale in our region. With this in mind, in August of 2010, the UVM Extension Northwest Crops and Soils Program initiated an organic hops variety trial at Borderview Research Farm in Alburgh, Vermont. The UVM Extension hop yard is trialing 22 publicly-available hop varieties and 3 additional varieties from Dr. John Henning's breeding program in Oregon. The goals of these efforts are to find hop varieties that demonstrate disease and pest resistance, high yields, and present desirable characteristics to brewers. Hops are a perennial crop – most varieties reach full cone production in year three. The results and observations from the first, second and third year hop variety trial can be found on the UVM Extension Northwest Crops and Soils website: **www.uvm.edu/extension/cropsoil/hops**. The following are the results from the fourth year of production.

MATERIALS AND METHODS

The replicated research plots were located at Borderview Research Farm in Alburgh, VT on a Benson rocky silt loam. The experimental design was a randomized complete block with three replicates; treatments were varieties. The hop yard was constructed in the spring of 2010 using 20' x 6" larch, tamarack, and cedar posts, with a finished height of 16'. Aircraft cable (5/16") was used for trellis wires. A complete list of materials and videos on the construction of the UVM Extension hop yard can be found at **www.uvm.edu/extension/cropsoil/hops**.

Four-foot wide hop beds were tilled with a moldboard plow, tilled again with a 3-point hitch 4' rotary tiller, and then planted with two vegetative hop cuttings per hill on 4-Aug 2010. Hills were distanced 7' apart, and rows were spaced at 10'. Each plot consisted of five consecutive hills.

Each year, rows are trained with two strings of coir (coconut fiber) per hill, with three to four of the strongest bines trained per string. In 2014, bines were trained between 26-May and 30-May.

Hop shoots

Scratching

Quality control

WEATHER

Using data from a Davis Instruments Vantage Pro2 weather station at Borderview Research Farm in Alburgh, VT, weather data was summarized for the months spanning from the 2013 harvest to the 2014 harvest.

DOWNY MILDEW MANAGEMENT

Downy mildew (*Pseudoperonospora humuli*) was identified in the hop yard in June of 2011. In the spring of 2013, a majority of the hills were "Scratched" as an early season preventative measure against downy mildew. Scratching is a practice initiated in the early spring when new growth has just emerged from the soil. The first shoots have an irregular growth rate and are not the most desirable for producing hop cones later in the season. Removal of this new growth and the top portion of the crown through mechanical means helps to remove downy mildew inoculum that has overwintered in the crown. The top of the crown itself can be removed to further eliminate overwintering downy mildew. This practice, which was implemented in the hop yard in 2014, is typically referred to as "Crowning". Crowning was performed using a DR trimmer fitted with a modified, blunted metal blade on 14-Apr 2014. A section of the hop yard was used to trial different crowning dates. Results from the 2014 Crowning Trial are available through our website.

Fungicides were sprayed when the forecast predicted weather favorable to downy mildew (warm and moist) (Table 1). The fungicides used in the research yard in 2014 were Champ WG (Nufarm Americas Inc, EPA Reg. No. 55146-1), and Regalia (Marrone Bio Innovations, EPA Reg. No. 84059-3). Champ WG is 77% copper hydroxide and works as a control measure against downy mildew in hops. When copper hydroxide is mixed with water, it releases copper ions, which disrupt the cellular proteins of the fungus. Regalia is a broad spectrum bio-fungicide that works by stimulating the plant's natural defenses. All pesticides applied were OMRI-approved for use in organic systems and were applied at rates specified by their labels using a Rear's Manufacturing Nifty Series 50-gallon stainless steel tank utility sprayer with PTO-driven mechanical agitation, a 3-point hitch, and a Green Garde® JD9-CT spray gun.

WEED MANAGEMENT

Hand-weeding and mulch were the primary weed control methods. Other weeding methods were studied this year as well in a section of the yard. Results from the 2014 Weeding Trial are available through our website.

ARTHROPOD MANAGEMENT

Arthropod scouting started in early June. Three leaves per hill and two hills per plot were scouted for insect pests and disease weekly in June, July, and August. Potato leafhoppers (*Empoasca fabae* Harris), two-spotted spider mites (*Tetranychus urticae* Koch), and aphids (*Aphis* spp.) were identified in the hop yard. Economic thresholds for potato leafhoppers in hops have not been documented, but with an in-depth literature review, it was determined that two leafhoppers per leaf may be economically damaging to hops. A fact sheet on potato leafhoppers in hops can be found at: **http://www.uvm.edu/extension/cropsoil/wp-content/uploads/Leaf_Hopper_Article.pdf**. Economic thresholds for two-spotted spider mites (TSSM) have been suggested in the Pacific Northwest to be 1-2 spider mites per leaf in June, or 5-10 per leaf in July, based on a study done by Strong and Croft in 1995. A fact sheet from Cornell Cooperative Extension on TSSM can be found here: **http://nehopalliance.org/wp-content/uploads/2011/08/Article-Two-Spotted-Spider-Mite.pdf**. Of late, some question has arisen on whether these TSSM thresholds are accurate (Weihrauch 2005). It is important to note that spraying to control pests also eliminates many beneficial arthropods that help keep pest populations in check. Always consider carefully whether pesticide application is necessary before spraying.

IRRIGATION AND FERTILITY MANAGEMENT

The hop yard was irrigated weekly in July and August at a rate of 3900 gallons of water per acre. Detailed information as well as a parts and cost list for the drip irrigation system can be found at **www.uvm.edu/extension/cropsoil/hops**. Fertigation (fertilizing through the irrigation system) was added this year as a way to save time and apply fertilizer more efficiently. It was conducted on one-half of the hop yard at a time. The east side of the yard was fertigated on 10-Jun, 28-Jun, and 4-Jul. The west side was fertigated on 16-Jun, 27-Jun, and 3-Jul. Eleven pounds of Ferti-Nitro Plus soy-based organic fertilizer with 13.5% nitrogen (N) were applied each time. Fertigation was timed to fit in with our normal irrigation schedule; the fertilizer was distributed evenly through 1500 gallons of water using a Dosatron unit. On 27-Jun Chilean Nitrate was applied to provide 46 lbs per acre of plant available N. All fertilizers were OMRI-approved for use in organic systems, and were applied at rates recommended in the Pacific Northwest (Gingrich et al., 2000).

Table 1: Spray schedule in the organic hop variety trial, Alburgh, VT 2014.

Date	Champ WG	Regalia
21-May	X	X
2-Jun	X	X
9-Jun	X	X
16-Jun	X	X
24-Jun	X	X
3-Jul	X	X
7-Jul	X	X
14-Jul	X	X
28-Jul	X	X

HARVEST

Hop harvest was separated by variety and targeted for when cones were at 20-25% dry matter. At harvest, hop bines were cut in the field and brought to a secondary location to be run through our mobile harvester. Three plots of each variety were measured. Harvest date for each variety can be found in Table 3. The number of living bines at the bottom and top of the coir were counted and recorded, as were bine height, and pre-pick bine weight. Bine height was measured, but it should be noted that at least 3 ft of growth were left in the field. Sidearm length was measured on each string at 5', 10' and 12', and averaged. Picked hop cones were weighed on a per plot basis, 100-cone weights were recorded, and moisture was determined using a food dehydrator. One bine from each plot was weighed before and after harvest to determine the weight of the plant relative to the hops. That bine material was then sent to the UVM soil testing lab to be analyzed for macro/micronutrients.

Hop cones were dried to 8% moisture, baled, vacuum sealed, and then stored in a freezer. Hop cones from each plot were analyzed for alpha and beta acids in our lab using spectrophotometry as per the American Society of Brewing Chemists (ASBC) Method of Analysis entitled Hops 6a. Hop Storage Index (HSI) was also measured using the ASBC Method of Analysis detailed in Hops 12.

Hop brewing quality data is presented as varietal averages across the trial. The brewing quality of each variety was compared to industry standards.

Yields are presented at harvest moisture and at 8% moisture on a per hill and per acre basis. Per acre calculations were performed using the spacing in the UVM Extension hop yard of 622 hills per acre.

Yields were analyzed using the PROC MIXED procedure in SAS using the Tukey-Kramer adjustment, which means that each variety was analyzed with a pairwise comparison (i.e. 'Cluster' statistically outperformed 'Cascade', Cascade statistically outperformed 'Mt. Hood', etc.). Pearson correlation coefficients (r) and probability levels for spider mite thresholds developed in the Pacific Northwest, brew values, and growth characteristics were performed across varieties. Pearson correlation coefficients (r) were also used to determine significance between these factors. Correlations were deemed significant at the $p<0.10$ level, and the Pearson correlation coefficient (r) was used to determine the degree of correlation, and whether it was a negative or positive correlation.

RESULTS

The winter of 2013-2014 was slightly warmer than the average, adding to the total number of Growing Degree Days (GDD's). The 2014 growing season (March-September) experienced 5,325 GGD's, 25 fewer than the 30 year average (1981-2010 data). Precipitation was slightly below average in the winter and spring months and slightly above average during the growing season. (Table 2).

Table 2: Temperature, precipitation, and Growing Degree Day summary, Alburgh, VT, October 2013 to September 2014.

	2013			2014								
Alburgh, VT	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.
Average temperature (°F)	51.1	35.1	20.0	16.8	19	22.2	43.0	57.4	66.9	69.7	67.6	60.6
Departure from normal	2.9	-3.1	-5.9	-2	-2.5	-8.9	-1.8	1.0	1.1	-0.9	-1.2	0.0
Precipitation (inches)	1.87	3.16	0.23	0.85	0.65	1.70	4.34	4.90	6.09	5.15	3.98	1.33
Departure from normal	-1.73	0.04	-2.14	-1.20	-1.11	-0.51	1.52	1.45	2.40	1.00	0.07	-2.31
Growing Degree Days (base 32°F)	652	144	15.95	30.55	14.4	25	330	789	1041	1171	1108	860
Departure from normal	150	-40	15.95	30.55	14.4	25	-54	33	27	-27	-31	2
Growing Degree Days (base 32°F)	652	144	16	31	14	25	330	789	1041	1171	1108	860
Departure from normal	150	-40	16	31	14	25	-54	33	27	-27	-31	2

Based on weather data from a Davis Instruments Vantage Pro2 with WeatherLink data logger. Historical averages are for 30 years of NOAA data (1981-2010) from Burlington, VT.

YIELD AND BINE GROWTH

Varieties Saaz, Tettnang and Willamette were harvested first, based on observation and preliminary dry matter testing. The last harvested varieties were Horizon, Sterling, Teamaker and Mt. Hood. The hop harvest window was from 11-Aug to 5-Sep (Table 3).

The variety Saaz was the tallest variety (4.6 m), although not statistically different from the others (Table 4). Glacier had the longest sidearms (57.4 cm).

Table 3: Organic hop variety trial harvest date and dry matter at harvest, Alburgh, VT 2014.

Variety	Harvest date	Harvest dry matter (%)
Saaz	11,14-Aug	28.1
Tettnang	14-Aug	50.8
Willamette	14,18-Aug	19.5
Perle	18,19-Aug	24.0
Chinook	19-Aug	21.8
Centennial	19,20-Aug	23.0
Fuggle	19,20-Aug	22.8
Cascade	25-Aug	23.8
Cluster	25-Aug	23.0
Galena	25-Aug	22.6
Vanguard	25,27-Aug	24.6
Liberty	27-Aug	20.8
Horizon	2-Sep	25.1
Sterling	2-Sep	24.0
Teamaker	2-Sep	24.4
Mt. Hood	4,5-Sep	23.5

Table 4: Bine height and side arm length, Alburgh, VT 2014

Variety	Bine height (meters)		Average sidearm length (cm)	
Cascade	4.1	a	54.7	ab
Centennial	4.3	a	27.0	ab
Chinook	4.0	a	48.8	ab
Crystal	3.6	a	23.5	ab
Fuggle	4.3	a	45.7	ab
Galena	4.5	a	48.6	ab
Glacier	4.3	a	**57.4**	a
Liberty	4.3	a	40.3	ab
Mt. Hood	4.3	a	41.5	ab
Newport	4.3	a	49.6	ab
Nugget	4.3	a	49.4	ab
Perle	4.2	a	33.1	ab
Saaz	**4.6**	a	17.3	b
Santiam	4.5	a	32.7	ab
Sterling	3.8	a	29.7	ab
Vanguard	4.3	a	46.4	ab
Willamette	4.2	a	38.0	ab
p-value	<0.0001		<0.0001	

*Note that the bottom three feet of each bine was not harvested and not included in this measurement. Within a column, values followed by the same letter are not significantly different. Values in **bold** indicate top performing varieties.*

More bines trained on the string were found to increase overall plant biomass, but not necessarily increase cone yield. Of the 3-4 healthiest looking bines that were trained per string, some of these bines had either died or untrained themselves, while additional bines self-trained. In 2013, a positive correlation was found between number of living bines left at harvest and pre-pick bine weight. There was no correlation between number of living bines at harvest and bine height or 100-cone weight (Table 5).

Table 5: Number of living bines at the base of the string at harvest and yield: Pearson correlation coefficients and probability levels, 2013 harvest, Alburgh, VT.

Measurement	Number of living bines at the base of the string at harvest	
	r	Probability level
Bine height	0.1034	0.444
Pre-pick bine weight	0.2413	0.0706
100-cone weight	0.1949	0.1461

Of the commercially available varieties, Cascade was highest yielding, producing 1.53 lbs of hops per hill at 8% moisture, or 953.1 lbs per acre. Saaz was the lowest yielding variety (Table 6, Figure 1). The top 5 varieties for yield per acre at 8% moisture were Cascade, Newport, Chinook, Horizon, and Centennial respectively (Figure 1).

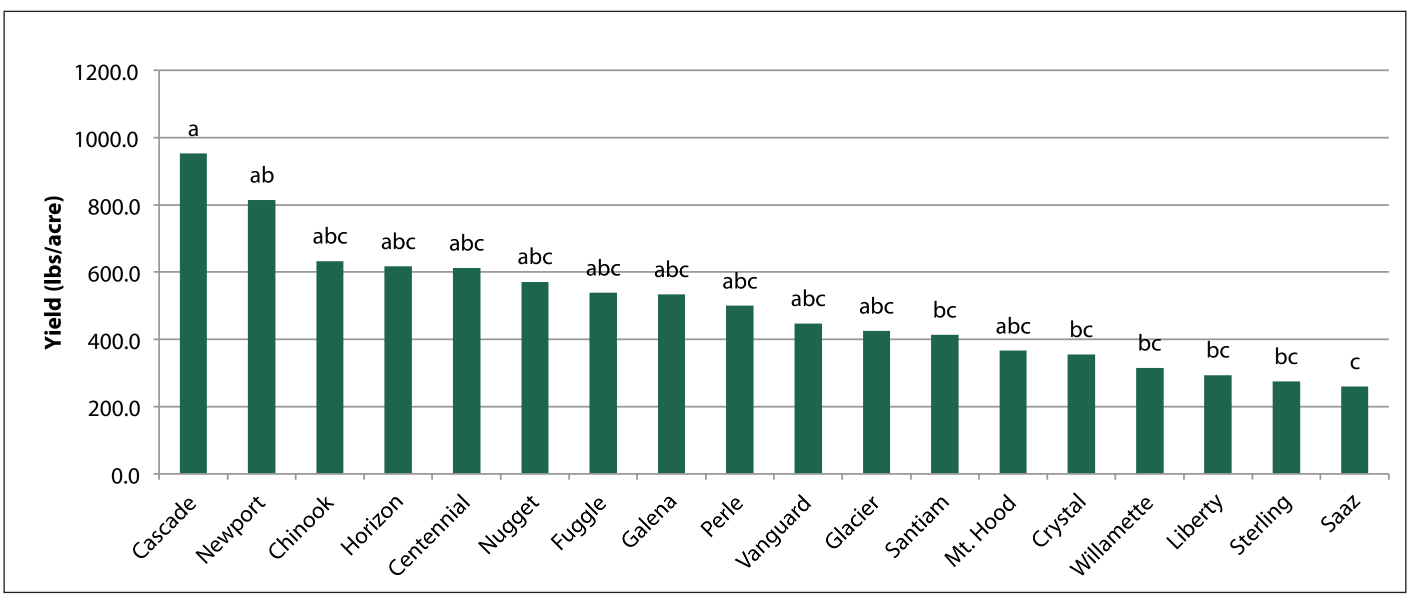

Figure 1: Plant yield in pounds per acre by variety, Alburgh, VT 2014.

Centennial had the largest cones of all the varieties, although it was not significantly different from Galena, Newport, or Santiam (Table 6). Glacier had the smallest cones.

Table 6: 100 cone weight and yields at 8% moisture, Alburgh, VT 2014.

Variety	100 cone		Yield per hill		Yield per acre	
Cascade	13.9	abc	**1.53**	a	**953.1**	a
Centennial	**19.4**	a	0.98	abc	612.4	abc
Chinook	13.7	abc	1.02	abc	632.6	abc
Crystal	11.4	bc	0.57	bc	354.8	bc
Fuggle	10.8	bc	0.87	abc	538.5	abc
Galena	18.3	a	0.86	abc	533.8	abc
Glacier	8.7	c	0.68	abc	425.4	abc
Horizon	15.8	ab	0.99	abc	617.3	abc
Liberty	10.2	bc	0.47	bc	293.6	bc
Mt. Hood	13.2	abc	0.59	abc	366.2	abc
Newport	18.9	a	1.31	ab	814.0	ab
Nugget	15.5	ab	0.92	abc	571.4	abc
Perle	11.9	bc	0.80	abc	499.8	abc
Saaz	13.0	abc	0.42	c	259.4	c
Santiam	18.9	a	0.66	bc	413.0	bc
Sterling	11.0	bc	0.44	bc	274.6	bc
Vanguard	14.9	abc	0.72	abc	447.9	abc
Willamette	8.9	bc	0.51	bc	314.6	bc
p-value	<.0001		.0064		.0064	

Within a column, values followed by the same letter are not significantly different. Values in ***bold*** *indicate top performing varieties.*

In 2013, a positive correlation was found between 100-cone weight and bine height, indicating that taller bines yield larger cones. A positive correlation was also found between 100-cone weight and pre-pick bine weight, indicating that plants with more biomass will also yield larger cones (Table 7).

Table 7: 100 cone weight: Pearson correlation coefficients and probability levels, 2013 harvest.

Measurement	100 Cone weight	
	r	Probability level
Bine height	0.241	0.071
Pre-pick bine weight	0.546	<0.0001

In 2013, a correlation was found between yield and bine height, indicating that taller bines lead to higher yields (Table 8). No correlation was found between yield and number of living bines at the base of the string at harvest, indicating that more bines per string does not necessarily lead to higher yields. A strong correlation was found for both pre-pick bine weight and 100 cone weight with regard to yield, meaning that plants with higher yields had higher pre-pick weight and 100 cone weight as expected (Table 8).

Table 8: Bine growth and yield: Pearson correlation coefficients and probability levels, 2013 harvest.

Measurement	Yield	
	r	Probability level
Bine height	0.392	0.003
Pre-pick weight	0.758	<0.0001
# living bines at the base of the string at harvest	0.138	0.307
100 cone weight	0.733	<0.0001

There were few significant differences in yields among the varieties (Table 6). This is likely due to the fact that yields varied considerably by plot (Table 9) For example, while Centennial averaged 612.4 lbs per acre across three plots (the fifth highest yield this year), the lowest yielding Centennial plot was 514 lbs per acre, a yield which 14 other varieties also reached or exceeded in at least one of their plots. The wide variation between plots of the same variety can be partly explained by the history of the yard. At the time of the hop yard establishment, each plot contained 5 hills with two crowns per hill. Over the last 3 years, a number of the hills have been killed by disease, insect, or other production pressures. Several of the plots also have hills that have been weakened from environmental and/or pest pressures. For example, the eastern section of our hop yard is shaded during the morning hours.

Table 9: Range of Yields by Variety, Alburgh, VT 2014.

Variety	Yield @ 8% moisture	
	Minimum	Maximum
Cascade	858	1103
Centennial	514	680
Chinook	380	1013
Cluster	518	518
Crystal	212	505
Fuggle	423	675
Galena	116.8	978
Glacier	376	476
Horizon	573	643
Liberty	227	328
Mt. Hood	297	425
Newport	552	1192
Nugget	397	722
Perle	419	550
Saaz	200	336
Santiam	352	516
Sterling	206	325
Teamaker	773	773
Tettnang	1259	1260
Vanguard	407	514
Willamette	86	640

BREWING QUALITY

Over half of the hop varieties met or exceeded the industry standard for alpha acids in 2014 (Table 10, Figure 2). All hop varieties met the industry standards for beta acids in 2014 (Table 10, Figure 3). In figures 2 and 3, red lines denote industry averages.

Table 10: Percent alpha acids, percent beta acids, and Hop Storage Index rating (HSI) by variety, Alburgh, VT 2014.

Variety	Alpha acids (%)	Beta acids (%)	HSI
Cascade	7.42	9.00	0.23
Centennial	10.56	5.16	0.24
Chinook	8.47	4.98	0.25
Cluster	7.41	4.92	0.22
Crystal	4.09	7.73	0.23
Fuggle	3.81	3.91	0.27
Galena	10.98	8.60	0.25
Glacier	5.73	9.56	0.23
Horizon	11.68	9.00	0.23
Liberty	4.00	4.46	0.24
Mt. Hood	4.69	8.24	0.21
Mt. Rainier	3.44	12.39	0.23
Newport	11.74	9.39	0.25
Nugget	13.12	5.11	0.24
Perle	9.11	7.06	0.26
Saaz	3.82	4.44	0.23
Santiam	4.45	8.51	0.21
Sterling	5.05	5.96	0.25
Teamaker	1.58	10.09	0.20
Tettnang	3.92	3.53	0.28
Vanguard	7.65	9.05	0.23
Willamette	4.17	4.48	0.28

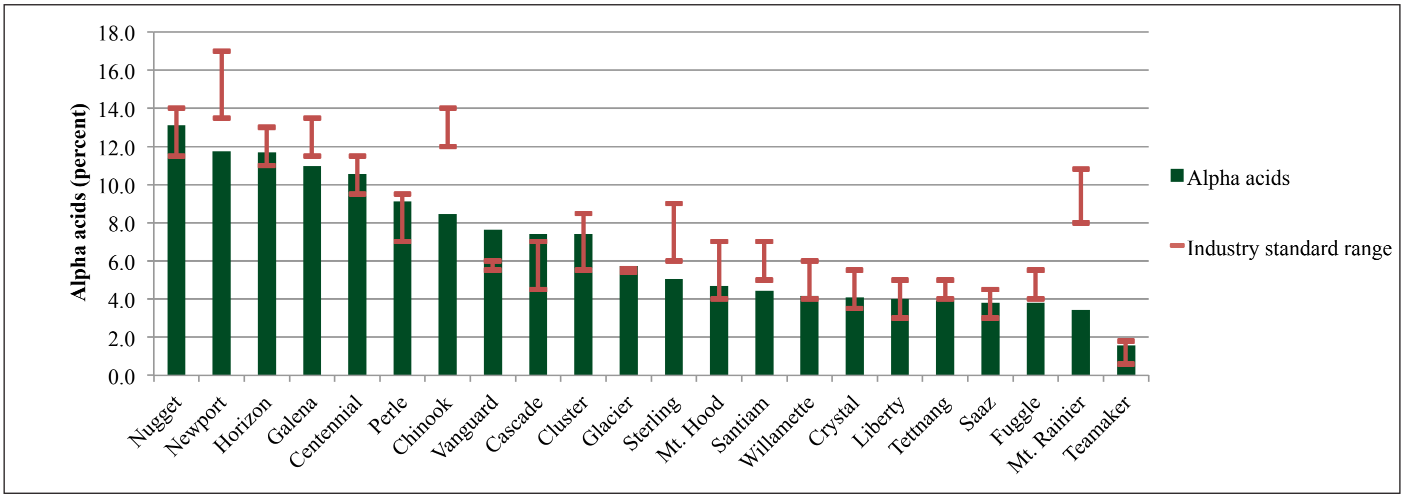

Figure 2: Alpha acid levels for hops from the 2014 harvest, Alburgh, VT. Industry standards based on information from USA Hops and Hopunion.

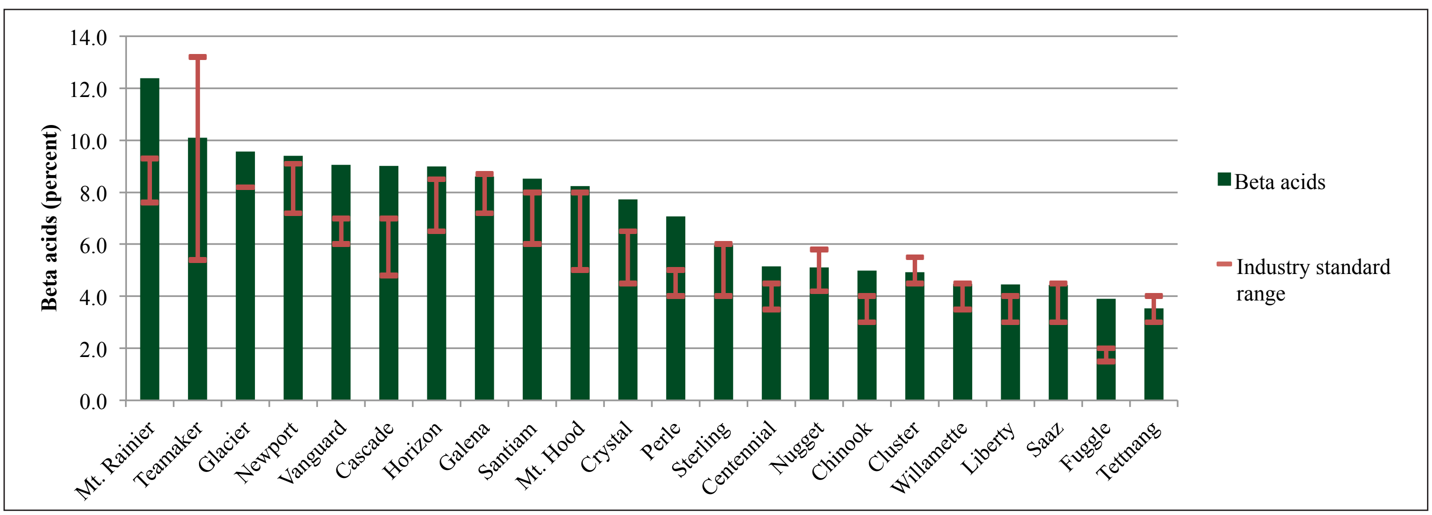

Figure 3: Beta acid levels for hops from the 2014 harvest, Alburgh, VT. Industry standards based on information from USA Hops and Hopunion.

HARVEST YEAR-TO-YEAR COMPARISONS

Yield comparisons between 2013 and 2014 show that every variety except Willamette increased in average yield this year (Figure 4). Varieties Liberty, Horizon, and Saaz more than tripled yield from 2013 to 2014. Crystal, Perle and Cascade more than doubled yield.

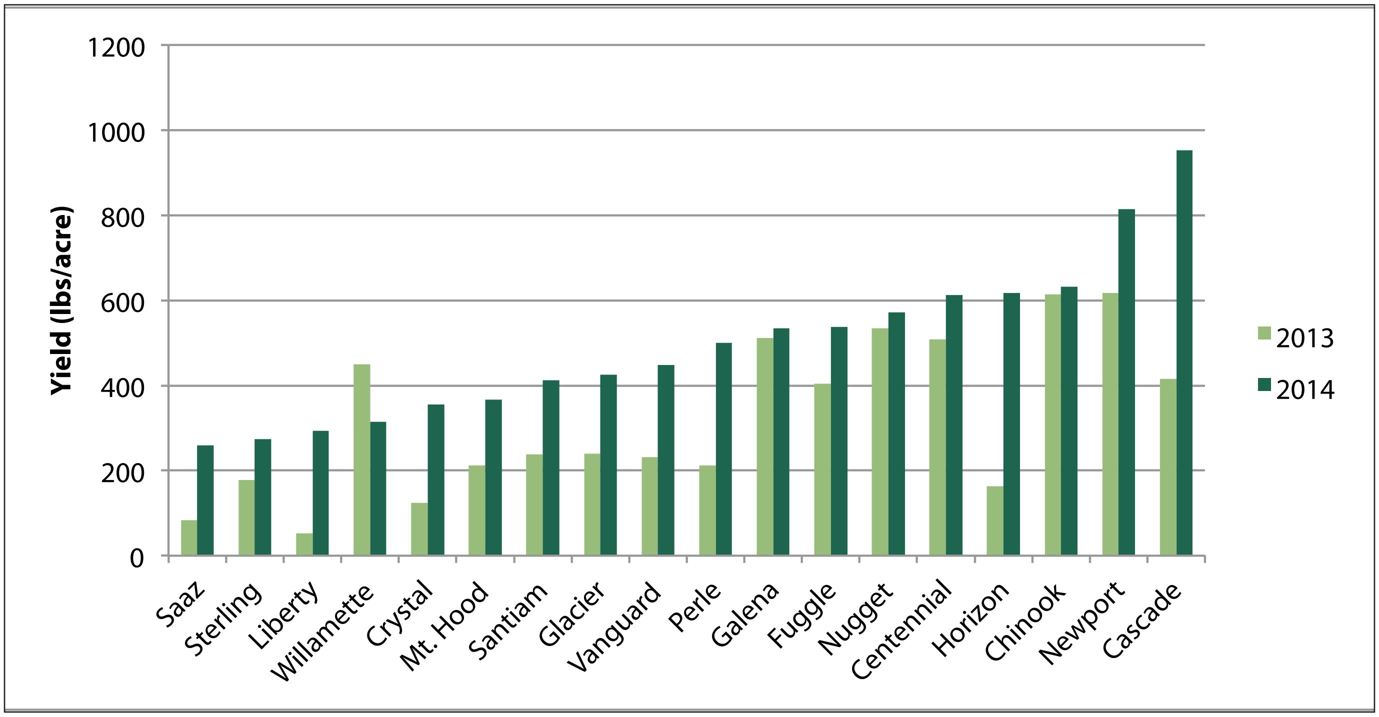

Figure 4: Yield comparison between 2013 and 2014 harvest, Alburgh, VT.

Alpha acids for all varieties except Galena, Nugget, Chinook and Willamette are higher in 2014 than they were in 2013 (Figure 5). Variability of alpha acids in a certain variety may indicate that the plant's cone quality is more easily impacted by variations in year-to-year growing conditions, the maturity of the plant, or water and nutrient deficiencies.

Some variability was also observed from year-to-year in beta acids, although overall they stayed pretty consistent. Galena, Chinook, Cluster, Centennial, Willamette, Sterling, Tettnang and Teamaker all have lower beta acids in 2014 than they did in 2013, but by a relatively small margin. This might indicate a stabilization of beta acid levels as the plants mature (Figure 6).

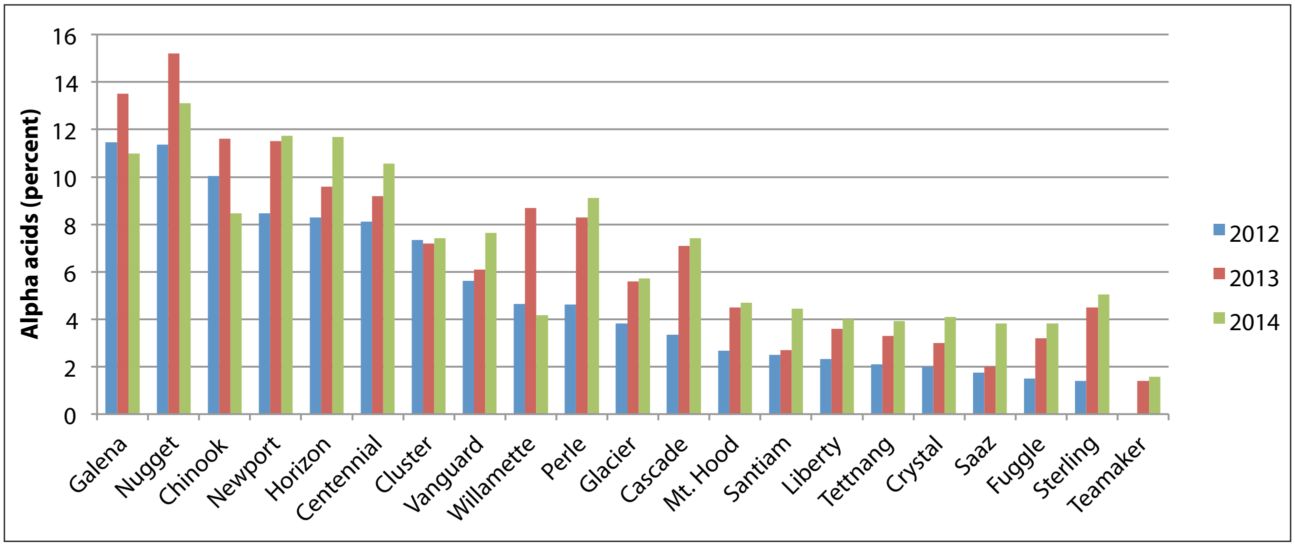

Figure 5: Alpha acid comparison between 2012, 2013 and 2014 harvest, Alburgh, VT.

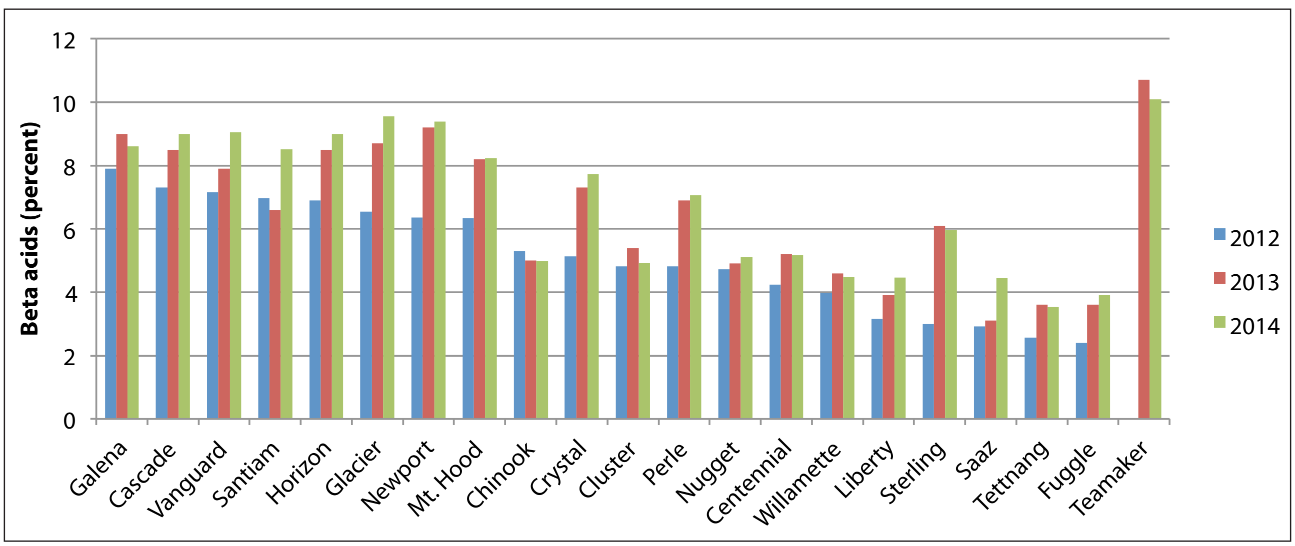

Figure 6: Beta acid comparison between 2012, 2013 and 2014 harvest, Alburgh, VT.

BINE NUTRIENTS

Ideally, 3% of the total plant biomass at harvest will be nitrogen, .05% phosphorous, and 2% potassium. In our variety trial, Galena had the highest percent nitrogen at 2.29% (Table 11, Figure 7). Newport had the highest percent phosphorous (0.53%). Potassium was highest in Liberty (1.81%). Galena, Newport and Liberty had the highest percentages in these same categories in 2013. Interestingly, most varieties were close to meeting the nutrient requirement for phosphorous and potassium while none of the varieties met the 3% nitrogen concentration. It is highly likely that yields are being limited by nutrient deficiences, especially nitrogen.

Table 11: Bine nutrients for 2014. Hops variety trial, Alburgh, VT.

Variety	Nitrogen (%)	Phosphorous (%)	Potassium (%)
Cascade	1.73	0.33	1.43
Centennial	1.71	0.31	1.13
Chinook	1.60	0.39	1.36
Crystal	1.71	0.34	1.51
Fuggle	2.05	0.39	1.55
Galena	2.29	0.46	1.76
Glacier	1.49	0.35	1.23
Liberty	2.27	0.37	1.81
Mt. Hood	1.81	0.38	1.57
Newport	1.77	0.53	1.57
Nugget	1.99	0.49	1.57
Perle	1.90	0.34	1.38
Saaz	1.94	0.40	1.54
Santiam	1.78	0.37	1.50
Sterling	2.07	0.40	1.56
Vanguard	2.03	0.43	1.68
Willamette	1.75	0.45	1.73

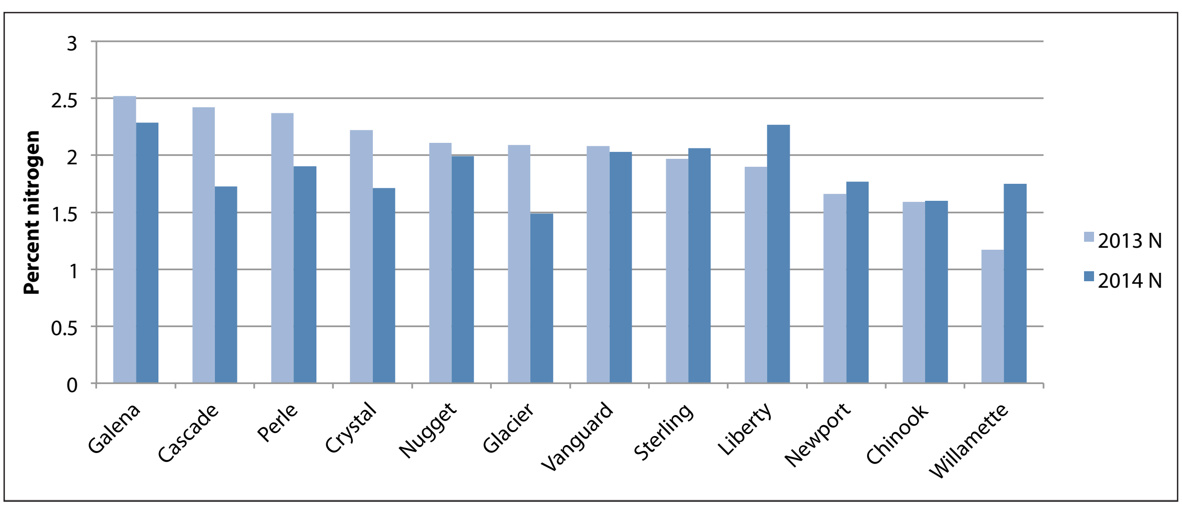

Figure 7: Percent Nitrogen in hop bines 2013 vs. 2014, Alburgh, VT.

Spider Mite Destroyer

Potato Leafhoppers

Two-spotted Spider Mites

ARTHROPODS

No organic pesticides were applied to the hop yard during the 2014 growing season. Pest populations in 2014 were such that spraying was not deemed necessary this year. Major pest populations throughout the 2014 growing season are shown in Figure 8.

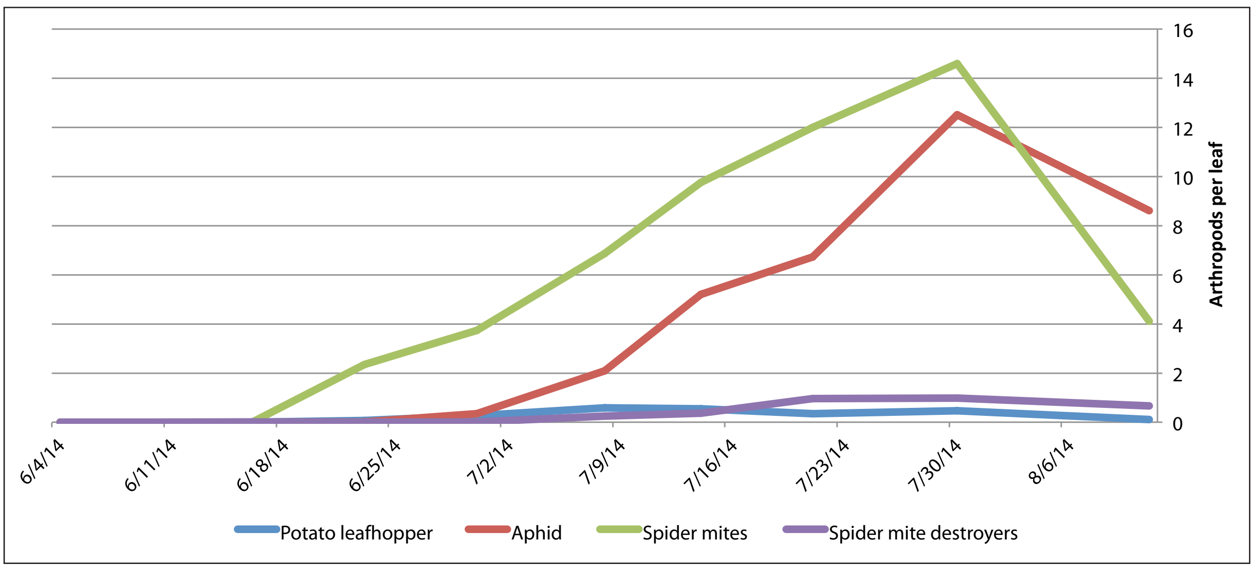

Figure 8: Average number of PLH, Aphids, TSSM and Mite Destroyers per leaf by sample date, Alburgh, VT 2014.

PEST PRESSURE – TWO-SPOTTED SPIDER MITES

Overall TSSM pressure in the hop yard was low in 2014. In 2013, relationship between TSSM and mite destroyers was assessed. There was not a significant interaction between TSSM and mite destroyers (Table 12) meaning that, statistically, mite destroyer populations did not correlate to TSSM populations. However, the classic boom-and-bust cycle of predator prey relationships was still present in 2013, as it was in 2014 (Figure 9).

Table 12: Pearson correlation coefficients and probability level: TSSM and mite destroyers, Alburgh, VT 2013.

Measurement	Two-spotted spider mites	
	r	Probability level
Mite destroyers	0.019	0.476

A slight significant difference was found between hop varieties for the two-spotted spider mite (TSSM) (Table 13). Mt. Hood had the highest levels of TSSM, while 074, Cascade, Fuggle and Teamaker had the lowest number of TSSM per leaf.

Populations of TSSM and mite destroyers differed significantly by sample date (Table 14). TSSM populations peaked in the hot, dry part of the season on 30-Jul.

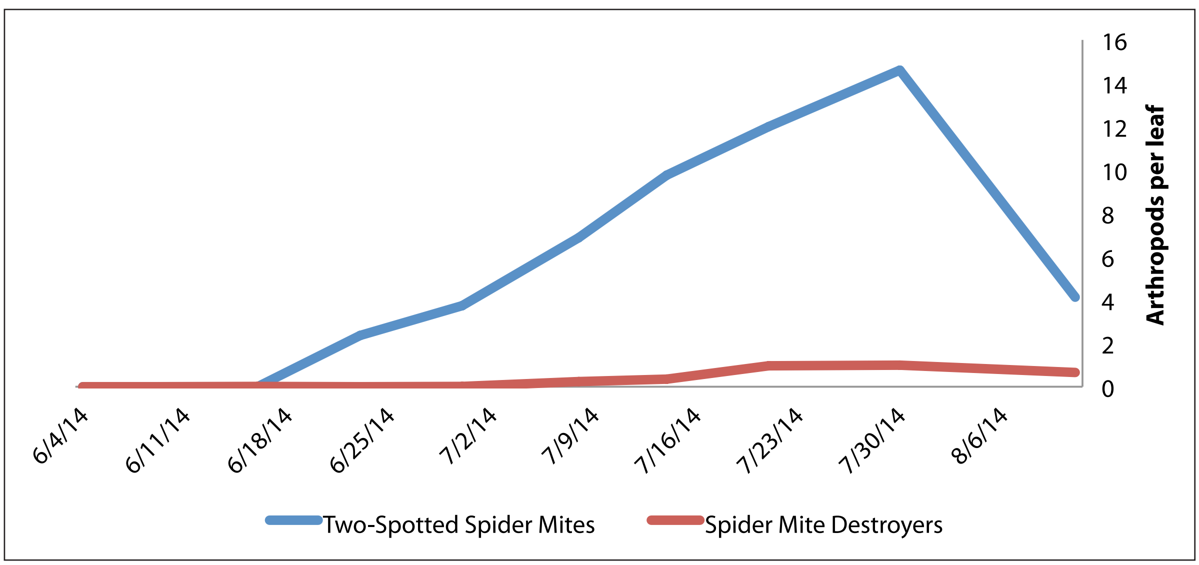

Figure 9: Average number of TSSM and mite destroyers per leaf by sample date. Alburgh, VT 2014.

Table 13: Average number of TSSM per leaf by variety, Alburgh, VT 2014.

Variety	Spider mites	
Mt. Hood	11.97	a
Galena	10.73	ab
Liberty	9.60	ab
Nugget	9.23	ab
Crystal	8.73	ab
Chinook	6.20	ab
Vanguard	5.80	ab
Willamette	5.17	ab
Horizon	5.07	ab
Newport	4.42	ab
Glacier	4.30	ab
Saaz	4.20	ab
Perle	4.00	ab
Sterling	3.77	ab
Centennial	3.60	ab
Santiam	3.17	ab
Cascade	2.23	b
Fuggle	1.83	b
Teamaker	0.76	b
p-value	0.0005	

Within a column, values followed by the same letter are not significantly different.

Table 14: Average number of TSSM and mite destroyer per leaf by sample date, Alburgh, VT 2014.

Sample date	Spider mites		Spider mite destroyers	
6/4/2014	0.00	d	0.00	c
6/9/2014	0.00	d	0.00	c
6/16/2014	0.00	d	0.01	c
6/23/2014	2.36	cd	0.00	c
6/30/2014	3.74	cd	0.00	c
7/8/2014	6.88	bc	0.24	bc
7/14/2014	9.76	ab	0.36	bc
7/21/2014	11.99	ab	0.96	a
7/30/2014	14.59	a	0.99	a
8/11/2014	4.12	cd	0.67	ab
p-value	<0.0001		<0.0001	

Within a column, values followed by the same letter are not significantly different.

PEST PRESSURE – POTATO LEAFHOPPERS

Compared to 2012 and 2013, there was a very low population of PLH in 2014. Average number of PLH varied significantly by hop variety across the 2014 season. Horizon had the least number of PLH, although all varieties were statistically similar except for Sterling (Table 15, Figure 10). The worst affected variety for PLH was Sterling.

Potato leafhopper arrived late to the Northeast in 2014, which was reflected by their presence in late June and July (Table 16, Figure 11). A significant difference was found between sample dates for PLH (Table 16), with the second week in July seeing the highest number of PLH per leaf (Figure 11).

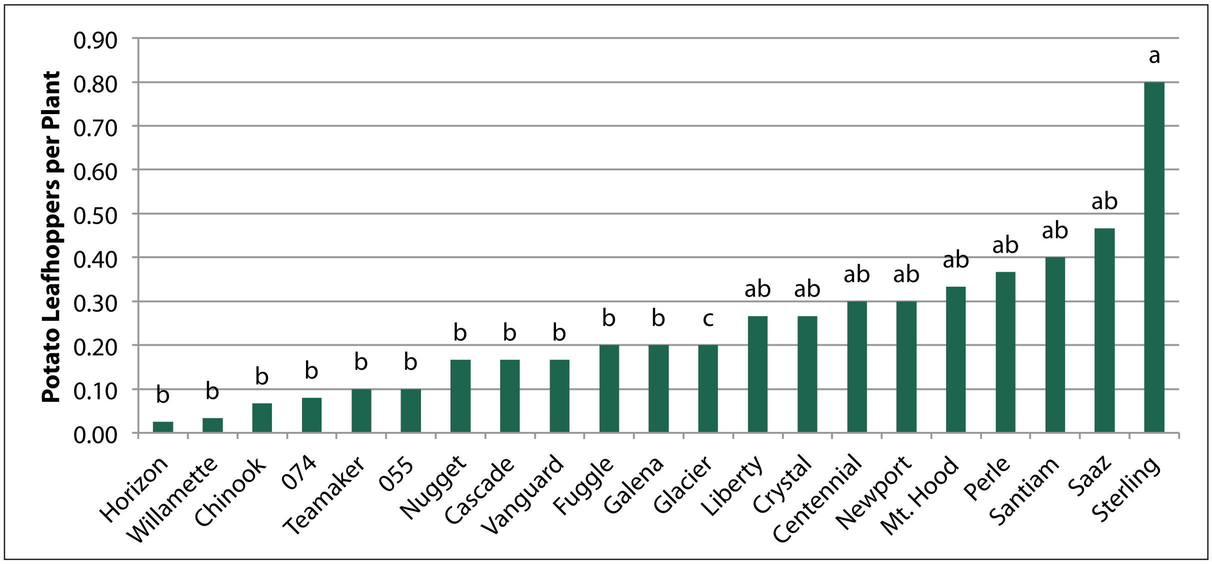

Figure 10: Average number of PLH per leaf by variety, Alburgh, VT 2014.

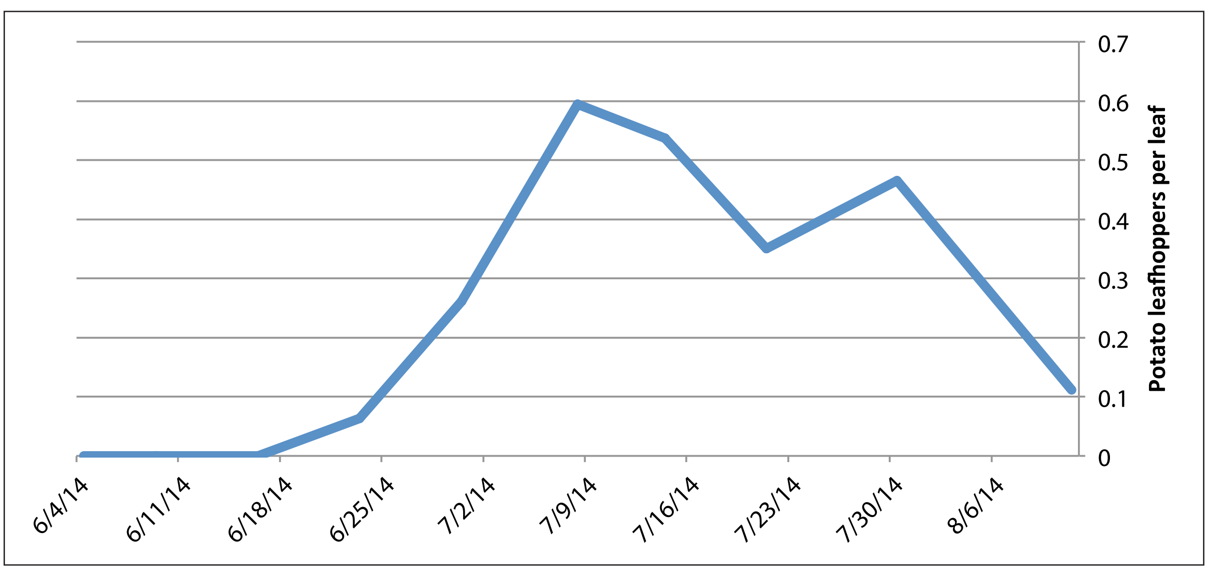

Figure 11: PLH incidence by sample date, Alburgh, VT 2014.

Table 15: PLH incidence by variety, Alburgh, VT 2014.

Variety	Potato leafhoppers per leaf	
Sterling	0.80	a
Saaz	0.47	ab
Santiam	0.40	ab
Perle	0.37	ab
Mt. Hood	0.33	ab
Newport	0.30	ab
Centennial	0.30	ab
Crystal	0.27	ab
Liberty	0.27	ab
Glacier	0.20	b
Galena	0.20	b
Fuggle	0.20	b
Cascade	0.17	b
Vanguard	0.17	b
Nugget	0.17	b
Teamaker	0.10	b
Chinook	0.07	b
Willamette	0.03	b
Horizon	0.02	b
p-value	0.0003	

Within a column, values followed by the same letter are not significantly different.

Table 16: PLH incidence by sample date, Alburgh, VT.

Sample date	Potato leafhopper	
6/4/2014	0.00	d
6/9/2014	0.00	d
6/16/2014	0.00	d
6/23/2014	0.06	cd
6/30/2014	0.26	bcd
7/8/2014	0.59	a
7/14/2014	0.54	ab
7/21/2014	0.35	abc
7/30/2014	0.47	ab
8/11/2014	0.11	cd
p-value	<0.0001	

Within a column values followed by the same letter are not significantly different.

PEST PRESSURE – APHIDS

Aphids were the most prevalent arthropod pest in our hop yard in 2014. However, they did not negatively impact yield or quality. There was no significant difference by variety across the 2014 season (Table 17, Figure 12). Aphid populations were the highest from early July to harvest time (Table 18, Figure 13).

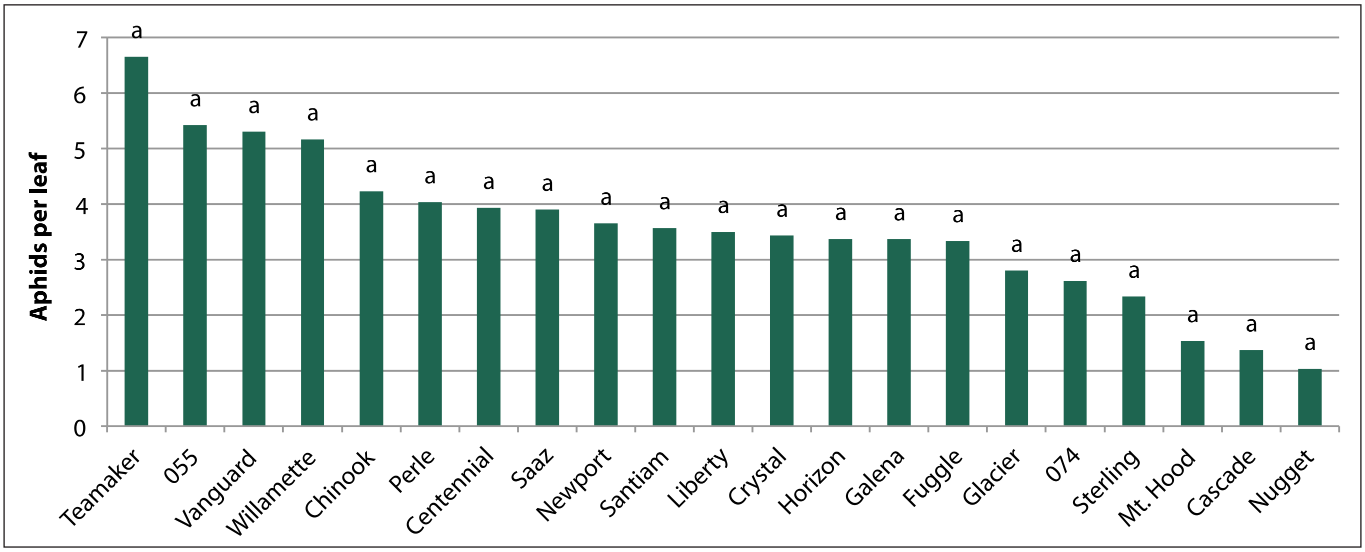

Figure 12: Average number of Aphids per leaf by variety, Alburgh, VT 2014.no sig diff

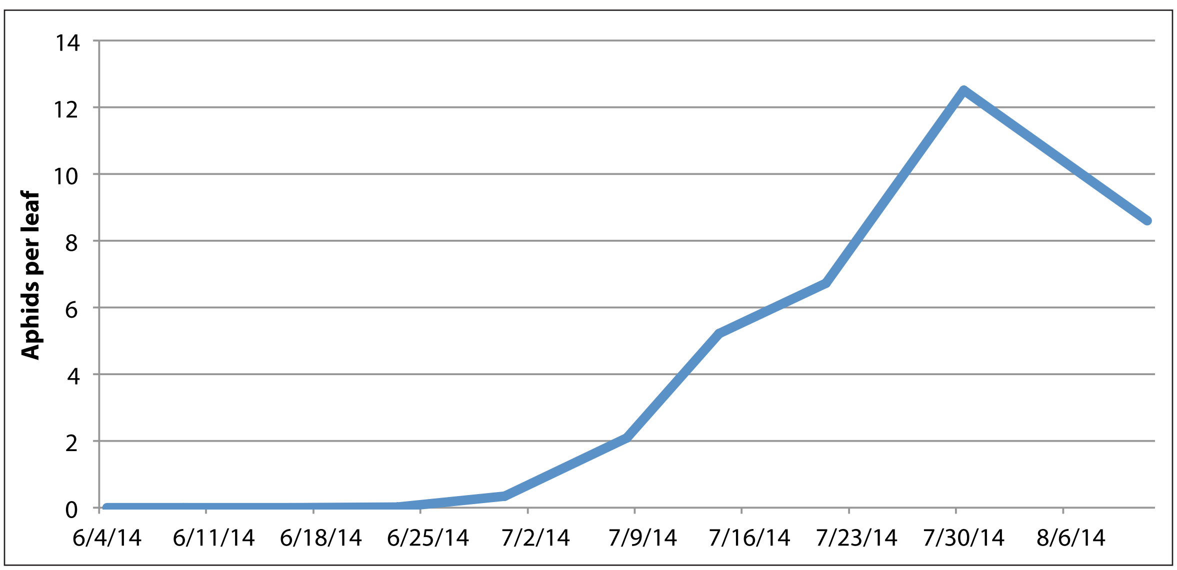

Figure 13: Aphid incidence by sample date, Alburgh, VT 2014.

Table 17: Aphid incidence by variety, Alburgh, VT 2014.

Variety	Aphid
Teamaker	6.7
Vanguard	5.3
Willamette	5.2
Chinook	4.2
Perle	4.0
Centennial	3.9
Saaz	3.9
Newport	3.7
Santiam	3.6
Liberty	3.5
Crystal	3.4
Horizon	3.4
Galena	3.4
Fuggle	3.3
Glacier	2.8
Sterling	2.3
Mt. Hood	1.5
Cascade	1.4
Nugget	1.0
p-value	NS

NS = difference between varieties was not statistically significant.

Table 18: Aphid incidence by sample date, Alburgh, VT 2014.

Sample date	Aphid	
6/4/2014	0.00	e
6/9/2014	0.00	e
6/16/2014	0.00	e
6/23/2014	0.02	e
6/30/2014	0.35	e
7/8/2014	2.09	de
7/14/2014	5.21	cd
7/21/2014	6.73	bc
7/30/2014	12.51	a
8/11/2014	8.60	b
p-value	<0.0001	

Within a column, values followed by the same letter are not significantly different.

DISCUSSION

YIELD

Yields continued to grow this year. Eight varieties produced above 500 pounds per acre of hops at 8% moisture in 2014. In comparison, there were 5 varieties that produced over 500 pounds per acre of hops in 2013, and in 2012, the top performing commercially available variety yielded less than 400 pounds per acre. In 2014, four varieties had yields over 1000 pounds per acre in at least one of their three plots (Table 9). One of those varieties, Cascade, averaged 953 pounds per acre. With 4 years of valuable learning experience behind us, we feel positive that higher yields can be achieved in the Northeast. There is no doubt that meeting water and nutrient needs is a challenge, and that we have some difficult pests to manage. However, improved management techniques continually show promise in enabling plants to reach their maximum potential. While yields in the Vermont research hop yard are consistently lower than standard yields in the Pacific Northwest, the difference is not the same across varieties. Top performing varieties in Vermont are different from top performing varieties in the PNW (Figure 14). This suggests that continued cultivation of varieties that are successful in this region, or breeding of new Northeast-specific varieties, could help to close the gap between Northeast and Northwest yield potential.

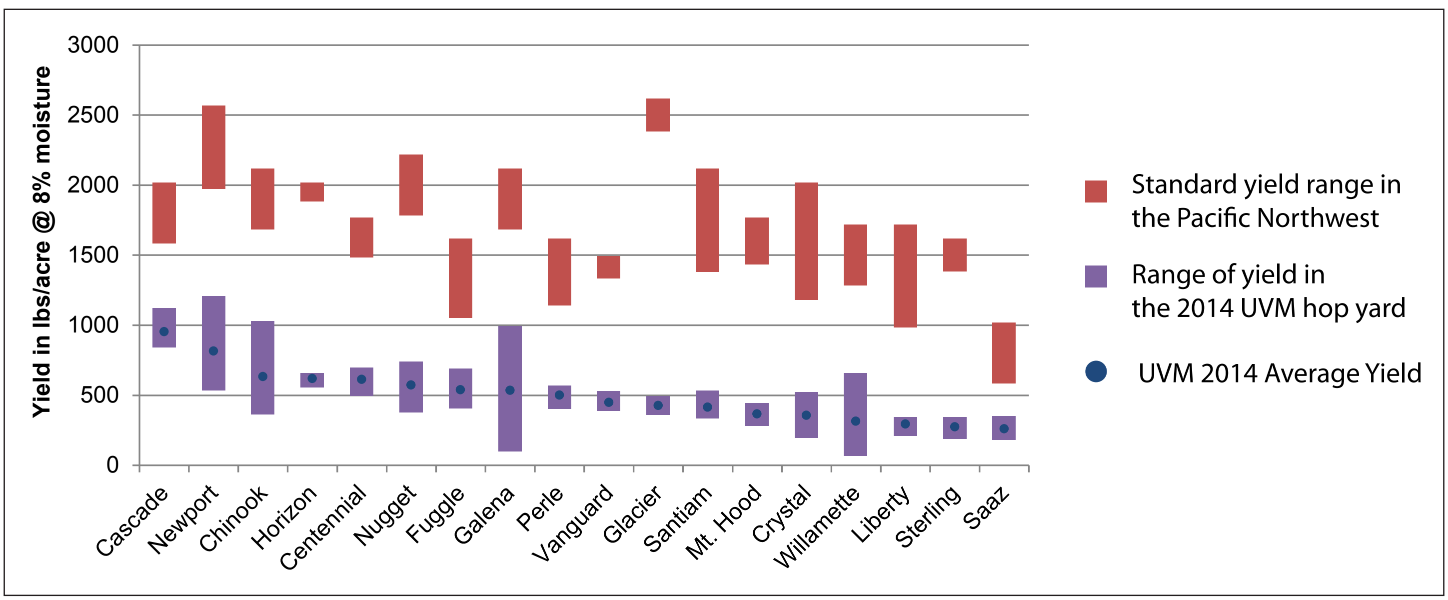

Figure 14: Range of yields in UVM hop yard compared against standard yields in the Pacific Northwest.

HIGHEST AND LOWEST YIELDING VARIETIES

Although there is some year-to-year variation in variety performance, trends over the history of the UVM hop yard show certain varieties that consistently perform among the best, and varieties that consistently perform among the worst. Table 19 shows varieties that ranked in the 5 highest yields in both 2013 and 2014, and the 5 lowest yields in both 2013 and 2014.

Table 19: Best and worst performing varieties, Alburgh, VT 2013-2014

High yield	Low yield
Centennial	Liberty
Chinook	Crystal
Newport	Saaz
	Sterling

BREWING QUALITY

Alpha acids from this year's harvest were, on average, higher than last year (Figure 5). Beta acids met the industry standard for all varieties, and appear to have reached a constant value (Figure 6). Lewis and Thomas (1982) found that high temperatures during flower initiation in the end of May and early June can cause high alpha acid levels, as this is when resin glands are initiated.

Hops, like grapes, have terroir (unique characteristics based on their specific soil and climate). Hop varieties grown on the East Coast, even though genetically the exact same as varieties grown in the Pacific Northwest or Europe, will not be like hops elsewhere due to different soils and different climates. Hops grown in the Northeast will present unique brewing characteristics. It is important to note that the hops from the UVM Extension research hop yard were only evaluated for alpha acids, beta acids, and HSI. No essential oil profiles were analyzed as it was cost-prohibitive. Further research is needed both at an industry-wide level and in the Northeast on the development of essential oils in hops, ranging from agronomic factors that affect essential oil development to the relationship between those essential oils and the final brewed product. Brew values produced in this trial will help brewers understand the quality profile displayed in this region. Continued data collection will help build a more accurate view of varietal profiles in the Northeast.

NUTRIENT MANAGEMENT

Hops are considered "heavy feeders", meaning they require a lot of nutrients. Split applications of volatile nutrients such as nitrogen (N) are highly recommended, particularly on lighter soils. Slow release amendments such as manures, composts, and various meals (blood, alfalfa, oilseed, etc.) will release plant available N (PAN) over time, but only under the right conditions. Hop N needs are greatest in the month of June and into early July when the plant is growing quickly (Figure 15). Split applications should be timed for early spring at training, and again in early- to mid-June. The fertigation system in the UVM hop yard, new in 2014, is intended to add available N more efficiently by applying fertilizer directly over the plant. Unfortunately, there are few rapidly available sources of N approved for use in organic farming systems and ready for application through a drip line, and they are expensive. The fertigation system seemed to work well this year, but less total N was applied because the plants matured earlier than usual. It is important to stop fertilizing when side arms begin to develop, because adding N after that time can divert the plant's focus to bine growth and away from cone production. Because of the early maturation and new strategy with the fertigation system, about 55lbs per acre of total N were applied in 2014, which is much lower than the 2013 season. Next year we will aim to apply more N.

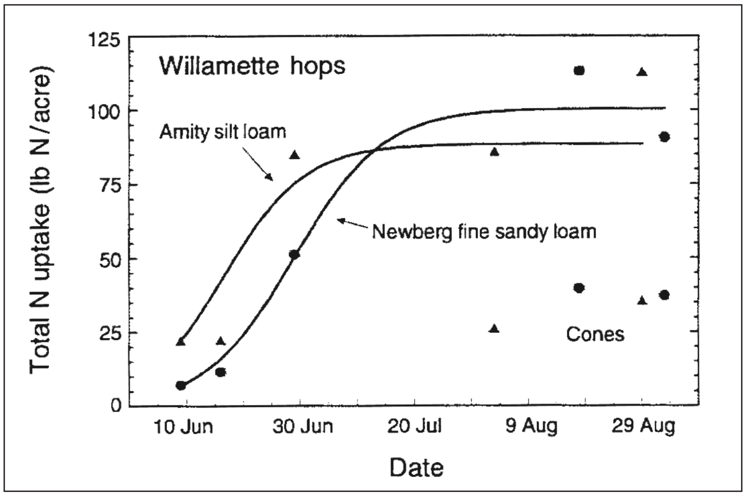

Figure 15: Rate of nitrogen uptake over time, Gingrich et al. 2000.

IRRIGATION

As hop production in the Northeast continues to evolve, it is becoming more and more apparent how essential irrigation is to obtaining high yields. Hops need 30" of water during the growing season, and while we often receive that much precipitation over the course of a year in the Northeast, it is not necessarily at the time when hops need it most. The summer of 2014 was not significantly drier than normal, and despite added irrigation, the available water may not have been sufficient to meet the crop's needs. The UVM irrigation system is limited by a well that is used for other farm needs in addition to the hop yard. More water would be added if available. In a study by Aroostook Hops in Maine, three-year-old Nugget plants with drip irrigation had three times the yield of the plants that were not irrigated (Delahunty and Johnston, 2011) Plants that are weakened due to water stress are also more susceptible to pest damage.

HILL SURVIVAL

In addition to yield performance, it is also useful to look at plant health over time. While quantity and quality of cones is often a good indicator of plant health, it may not always correlate to long term success. Figure 16 shows hill failures by variety over the four year lifetime of the UVM hop yard. Hill failure can occur for many reasons, for example one Cascade plot in the UVM hop yard receives more shade than the rest of the yard. However, for varieties like Cluster and Tettnang that have had significant failure, it is likely that they are not well suited for Vermont's specific climate and/or pest pressure.

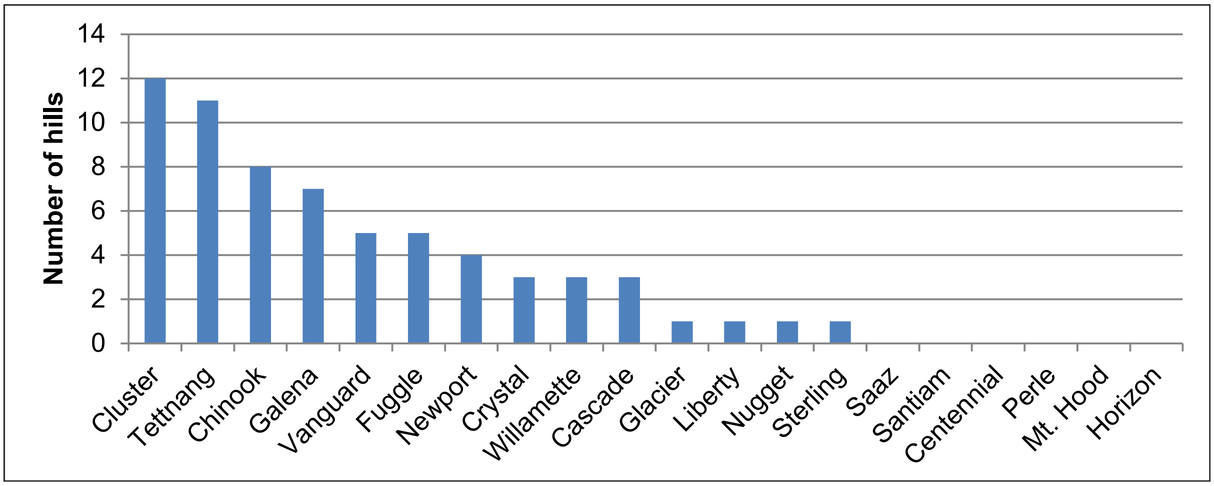

Figure 16: Hill failures by variety, Alburgh, VT 2010-2014.

HARVEST AND PROCESSING

This year in the UVM Extension hop yard, we completed our transition to using the mobile harvester for the entire crop instead of harvesting some plots by hand. In past years, for a ¾ acre hop yard, it took 7 motivated individuals approximately a month to harvest the entire yard by hand. That shows just how economically unfeasible it is to hand harvest, especially with short windows of opportunity for optimum harvest dry matter. The mobile harvester does a wonderful job in ensuring the cones stay intact and do not lose quality. In a 2012 comparison, we did not see any yield loss when comparing mobile harvesting to hand harvesting.

Hops were ready earlier than usual in the 2014 season. Growers across the country also saw their hops flower early; the reason for this is unknown, but we do know that hops are affected by the length and temperature of their winter dormant period. If each grower who experienced this had a shorter or warmer than usual winter, it could explain the change. As noted earlier, harvest was targeted for when the cones reached between 20-25% dry matter. Varieties reached appropriate dry matter and were harvested from 11-Aug to 5-Sep. In 2013, the harvest window was 21-Aug to 9-Sep, and in 2012 it was 16-Aug to 18-Sep. Limitations in equipment availability and labor always make for some shuffling in harvest date, but hops were generally harvested on time this year. Our harvest timing on the East Coast is likely different than standards for the PNW and there is no literature for harvest date in the Northeast. Paying close attention to dry matter and harvesting within the 20-25% window has worked well. Murphy and Probasco (1996) have found that a 2% increase in dry matter can result in a 9% increase in production (lbs/acre). Alpha acid content and essential oil levels are also affected by harvest timing. Total essential oils continue to develop well beyond normal harvest dates, whereas alpha acids degrade as harvest date is pushed back (Murphy and Probasco, 1996). In fact, Bailey et al (2009) found that late-harvested hops rated better in aroma quality, and beers brewed with late harvested hops were also rated better, described as more palate-full with a more pleasant bitterness, and more intense hop flavor and aroma. It would be very interesting to see what the essential oil content is like in the UVM Extension hop yard, but currently the program does not have the budget to test for essential oils.

ARTHROPODS

Timing is important when developing integrated pest management strategies. Annual tendencies should allow you to predict when certain pests will likely show up, or rapidly increase in number. Weather condition can help gauge what pests will be more prevalent at certain times. For example, TSSM thrive in hot and dry conditions, usually later in the growing season (late July to harvest time). In contrast, aphids prefer cool and wet conditions such as those experienced throughout the 2014 growing season.

TSSM were not a very significant pest in the UVM Extension research hop yard, but they have been in the past. Strong and Croft (1995) established TSSM thresholds of 1-2 mites per leaf in June, or 5-10 per leaf in July if no predators are present. Further studies performed more recently by Weihrauch (2005) suggest that hops may be able to tolerate >90 mites per leaf without suffering economic loss.

Significance was determined between varieties for TSSM and mite destroyers. Differences between varietal susceptibility to TSSM are well known, and have a genetic component. Research has indicated that there are differences in TSSM fecundity living on host plants of differing varieties, and that varieties have different susceptibilities to TSSM (Peters and Berry, 1980b). Peters and Berry (1980a) found that leaf characteristics such as hair and gland density affected TSSM oviposition rates, development rates, and sex ratios. Regev and Cone (1975) found that varieties vary in the susceptibility to TSSM based on their chemical differences, namely levels of farnesol. The industry acknowledges differences between the varieties, for example, according to the Hopunion Directory of Hop Data, Chinook and Fuggle are known as being "not excessively sensitive to insects," while Nugget is sometimes characterized by being susceptible to spider mites, and Tettnang is classified as "sensitive" to mites.

The hop aphid was much more abundant in 2013 and 2014 than in previous years; in 2011 and 2012 very few aphids were observed in the hop yard. During these years the weather was drier and hotter than average throughout the entire growing season. Aphids prefer a cool climate and in 2013 and 2014 cool conditions were experienced throughout much of the growing season. Even though populations were high at some points throughout the season, they were not large enough to warrant pesticide usage, based on our discretion. This example illustrates how important insect scouting can be. If outbreaks had persisted or increased further, there is a chance that our hop cones could have been impacted by sooty mold. Aphids have the ability to secrete a sugary solution, called "honey dew," directly into hop cones. This secretion provides a perfect habitat for sooty mold. Sooty mold can cause significant economic damage to hop cones, and is the reason that aphids must be watched closely in a hop yard.

Research shows that certain hop varieties are more succeptible to aphids than others (Campbell 1983, Dorschner and Baird 1988, Weirauch and Moreth 2005). Kralj et al. 1998 shows a relationship between high essential oil content and higher succeptibility to aphids, suggesting that the aphids feed on certain essential oils and are attracted to those plants with more available.

The fact that PLH may prefer certain hop varieties over others is a new discovery (Figure 10, Table 15). Potato leafhoppers, native to the eastern United States, are not an economically problematic pest in the major hop growing regions of the world. However, the UVM Extension hop yard is located within a grass/alfalfa field where these pests already live. Leafhoppers pierce the leaf tissue and suck out water and nutrients. The saliva that is left behind by this action can block the leaf veins, preventing nutrients from reaching the tips of the leaf and causing leaf necrosis. This occurred to varying degrees throughout the season, and in severe cases led to "hopper burn". To the best of our knowledge, there are no established economic threshold levels for leafhoppers in hops. Reviews of threshold levels for raspberries, potatoes, and alfalfa resulted in the establishment of a threshold level of two leafhoppers per leaf, although whether this will translate as an acceptable PLH threshold level for hops remains to be seen. An informational article on potato leafhoppers in hops can be found on the UVM Extension Northwest Crops and Soils Program website: **http://www.uvm.edu/extension/cropsoil/wp-content/uploads/Leaf_Hopper_Article.pdf**. At this time, it is unknown what draws leafhoppers to certain varieties or perhaps repels them from another. There are physical differences between hop leaves by variety, as demonstrated by research on TSSM (Peters and Berry, 1980a). These physical differences are known to provide resistance to PLH in alfalfa, potato and dry bean plants. Leafhopper-resistant alfalfa varieties have been developed and reduce the need for pesticide application. These resistant varieties have dense hairs that exude a chemical that deters leafhopper nymphs.

A relationship was found between alpha/beta acid levels and the number of PLH (Figure 17, Figure 18). As alpha and beta acid levels increase, average number of PLH per leaf decreases. At this stage it is undetermined whether this is an indicator of PLH preferring lower alpha varieties, or if PLH cause lower alpha acid content in hops. Other possibilities for varietal preference among PLH include hop growth characteristics or nutrient levels acting as a deterrent or attractant. UVM Extension continues to look into the interaction between PLH and hops.

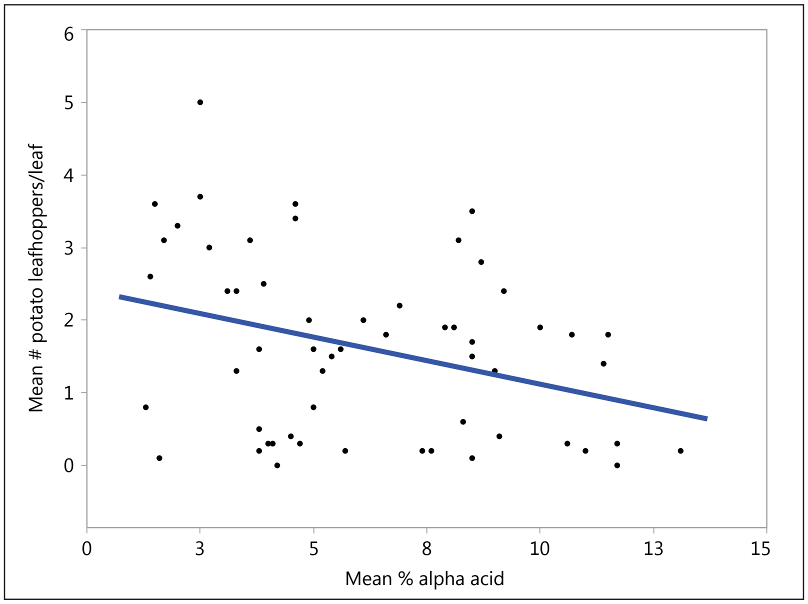

Figure 17: Relationship between alpha acid levels and average # of PLH per leaf, Alburgh, VT 2014.

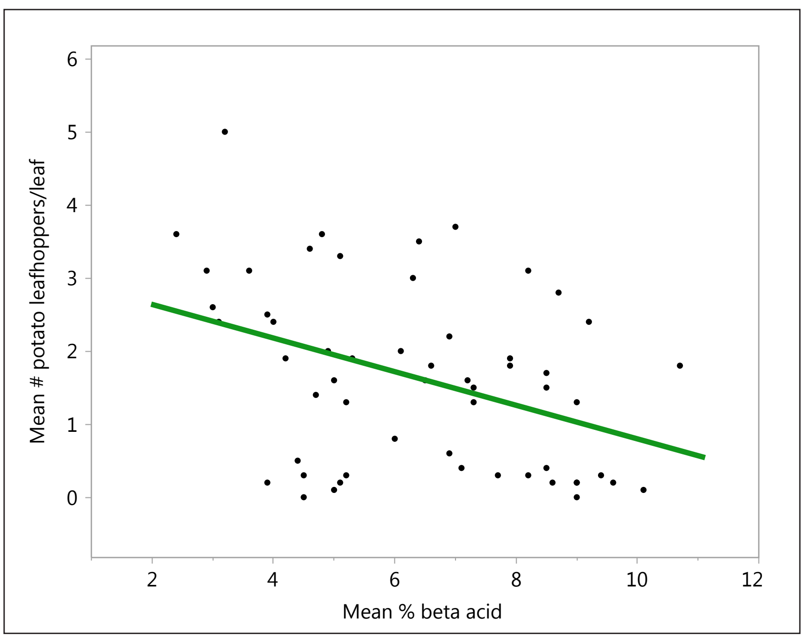

Figure 18: Relationship between beta acid levels and average # of PLH per leaf, Alburgh, VT 2014.

ACKNOWLEDGEMENTS

The UVM Extension Crops and Soils Team would like to thank the Borderview Research Farm run by Roger Rainville and his staff for their generous help with the trials. We would like to thank Conner Burke, Julija Cubins, Hannah Harwood, Ben Leduc, Laura Madden, Dana Vesty and Emily Whalen for their assistance with data collection and entry. This work is made possible through the USDA Organic Agriculture Research and Extension Initiative Grants Program; Vermont Department of Agriculture, Food, and Markets; Massachusetts Department of Agricultural Resources; the Specialty Crops Block Program; The Environmental Protection Agency; and the Northeast Integrated Pest Management Center.

Any reference to commercial products, trade names, or brand names is for information only, and no endorsement or approval is intended.

WORKS CITED

Bailey, B., C. Schonberger, G. Drexler, A. Gahr, R. Newman, M. Poschl, E. Geiger. 2009. The influence of hop harvest date on hop aroma in dry-hopped beers. Master Brewers. Asso. Of Amer. Tech. Qrtly. (doi:10.1094/TQ-46-2-0409-01).

Campbell, C. (1983). Antibiosis in hop (Humulus lupulus) to the damson-hop aphid, Phorodon humuli. Entomol. exp. appl., 33, 57-62.

Costello, M.J. 2007. Impact of sulfur on density of Tetranychus pacificus (Acari: Tetranychidae) and Galendromus occidentalis (Acari: Phytoseiidae) in a central California vineyard. Exp. Appl. Acarol. 42:197-208.

Delahunty, Krista and Johnston, Jason, "An Experiment on the Effectiveness of Irrigation and

Cover Cropping to Produce Sustainable Hops in Maine", 2011. **http://aroostookhops.com/uploads/SAREFinalReport2012FNE11-711.pdf**

Dorschner, K., & Baird, C. (1988). Susceptibility of hop to Phorodon humuli. Entomol. exp. appl., 49, 245-250.

Gingrich, G., J. Hart, N. Christensen. 2000. Hops: Fertilizer Guide. Oregon State University Extension & Station Communications.F.G.79. < **http://extension.oregonstate.edu/**>

Jones, G., C.A.M. Campbell, B.J. Pye, S.P. Maniar, A. Mudd. 1996. Repellent and Oviposition-Deterring Effects of Hop Beta-Acids on the Two-Spotted Spider Mite (Tetranychus urticae). Pestic. Sci. 47:165-169.

Kralj, D., Kac, M., Dolinar, M., Zolnir, M., & Kralj, S. (1998). Marker-assisted hop (Humulus lupulus L.) breeding. Monatsschrift fur Brauwissenschaft, 7, 111-119.

Lewis, P.A. and G.G. Thomas. 1982. Investigation into some causes of differing alpha-acid content of hop (Humulus lupulus L.) samples. J. of Hort. Sci. 57(1):121-127.

Murphy, J.M. and G. Probasco. 1996. The development of brewing quality characteristics in hops during maturation. Master Brewers Asso. Amer. Tech. Qrtly. 33(3):149-158.

Peters, K.M. and R.E. Berry. 1980a. Effect of hop leaf morphology on twospotted spider mite. J. Econ. Entomol. 73:235-238.

Peters, K.M. and R.E. Berry. 1980b. Resistance of hop varieties to twospotted spider mite. J. Econ. Entomol. 73:232-234.

Strong, W.B. and B.A. Croft. 1995. Inoculative release of Phytoseiid mites (Acarina: Phytoseiidae) into the rapidly expanding canopy of hops for control of Tetranychus urticae (Acarina: Tetranychidae). Environ. Entomol. 24(2):446-453.

Weihrauch, F. 2005. Evaluation of a damage threshold for two-spotted spider mites, Tetranychus urticae Koch (Acari: Tetranychidae), in hop culture. Ann. of Appl. Biol. 146:501-509.

UVM Extension helps individuals and communities put research-based knowledge to work.

Weihrauch, F., & Moreth, L. (2005). Behavior and population development of Phorodon humuli (Schrank) (Homoptera: Aphididae) on two hop cultivars of different susceptibility. J. Insect Behavior., 18(5), 693-705.